Applying Inquiry Skills

12. One method for determining the length of a swing without measuring it would be to measure the time for one cycle (T). Use the pendulum equation to solve for length (l).

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$l = \frac{T^2}{4\pi^2}g$$

6.2 WAVE MOTION

Investigation 6.2.1 Wave Transmission: Pulses on a Coiled Spring

(Pages 203–205)

Purpose

The purpose of this investigation was to study pulses travelling along springs/ropes and their characteristics and then apply these characteristics to waves in order to understand their behaviours.

Question

(i) How do pulses move along a coiled spring?
(ii) How are pulses reflected from a fixed-end and a free-end?

Hypothesis/Prediction

(i) Pulses travel along a coiled spring through the motion of the individual coils which move back and forth as the pulse travels past a certain point.
(ii) Since the pulses are travelling along a material object, it is expected that some energy should be lost along the path due to friction. As such, the amplitude of the reflected pulse will likely be smaller than the amplitude of the original pulse, but the amplitude itself will not likely affect the speed of the pulse.
(iii) In step 8, as the tension of the spring is increased (i.e. the spring is stretched further), the speed of the pulses will increase since the spring is tighter.

Design

In this investigation, a coiled spring was stretched across the floor and subjected to various conditions (length of stretch, pulse amplitude, pulse phase, condition of end) as pulses were generated by the motion of a student's hand. The motion of the coils and behaviour of the pulses sent (speed, amplitude, phase) was observed. The following variables and controls applied in the various cases (note that part (d) was completed only if various spring types were available):

Case	Independent Variable	Dependent Variable	Controls
(a)	type of end (fixed or free)	reflected pulse phase	incident pulse phase, amplitude, spring tension
(b)	incident pulse amplitude	speed of pulse	spring tension, pulse phase, type of end
(c)	spring tension	speed of pulse	pulse amplitude, pulse phase, type of end
(d)	spring type	speed of pulse	spring tension, amplitude, pulse phase, end type

Materials

- coiled spring (Slinky toy)
- piece of paper
- various spring types (if available)
- masking tape
- stopwatch
- metre stick
- 4.0-m string

Procedure

1. A piece of masking tape was attached to the middle of the spring which was then stretched along a smooth floor to a length of 2.0 m with one end held rigidly. A rapid sideways jerk (transverse pulse) was generated at the other end and the motion of the coils was observed by watching the tape attached to the spring coil.
2. A rapid forward push (longitudinal pulse) was generated at the fixed end and the motion of the coils was observed by watching the tape attached to the spring coil.
3. A folded piece of paper was placed standing on the floor near the spring at the middle of its length. A transverse pulse was generated in order to knock down the piece of paper as it travelled along the spring.
4. Holding one end of the spring rigid (creating a fixed-end), a positive transverse pulse was generated and allowed to travel towards the other end and reflect from it. The phase of the reflected pulse was observed and recorded.
5. A piece of string 4.0 m long was attached to one end of the spring (creating a good approximation to a free-end) with the other end of the string held rigid and the spring stretched 2.0 m. A positive transverse pulse was generated and allowed to travel towards the end attached to the string and then reflect from this boundary. The phase of the reflected pulse was observed and recorded.
6. The string was removed and one end of the spring was again held rigid with the spring stretched 2.0 m. A transverse pulse was generated and the time taken for it to travel to the other end was measured. This was repeated twice to improve accuracy. Then the time taken for the same type of pulse to travel to one end of the spring and back again was measured three times.
7. Using an amplitude of 15 cm, the time taken for one transverse pulse to travel to the other end of the spring and back was measured three times. This was repeated using amplitudes of 30 cm and 45 cm.
8. Using an amplitude of 15 cm and spring lengths of 2.0 m, 3.0 m, and 4.0 m, the time taken for a transverse pulse to travel to the other end and back was measured and repeated twice each time for accuracy.
9. Using three different springs, each of different “weights” (light, medium, heavy) and stretched 2.0 m, a transverse pulse with an amplitude of 15 cm was generated and the time taken for it to travel to the other end and back was measured. This was repeated twice for each spring to improve accuracy.
10. All equipment was returned and waste disposed of or recycled.

Observations

In step 1 of the procedure, it was observed that the piece of masking tape moved side to side, perpendicular to the length of the spring as the transverse pulse went past. From this, it can be said that all the coils of the spring move perpendicularly to the length of the spring as the transverse pulse passes.

In step 2, it was observed that the piece of masking tape moved backwards and forwards, parallel to the length of the spring as the longitudinal pulse went past. From this, it can be said that all the coils of the spring move parallel to the length of the spring as the longitudinal pulse passes.

In step 3, it was observed that the piece of paper was knocked over by the pulse as it travelled past the paper. The energy required to do this came originally from the sideways motion of the experimenter’s hand and it was transmitted as an energy pulse by the coils of the spring as the spring moved from side to side.

In step 4, when a positive transverse pulse was transmitted along the spring towards a fixed-end, it was observed that the reflected pulse was a negative pulse, i.e. the reflected pulse was inverted with respect to the incident pulse when it reflected from a fixed-end.

In step 5, when a positive transverse pulse was transmitted along the spring towards a free-end, it was observed that the reflected pulse was also a positive pulse, i.e. the reflected pulse was in phase with respect to the incident pulse when it reflected from a free-end.

Table 1 illustrates observations made is step 6 of the above procedure.

Table 1 Motion of a Pulse Along the Length of a Spring and Back

Trial	Incident pulse only time (s)	Incident and reflected pulse time (s)	Reflected pulse only time (s)
1	0.80	1.55	0.75
2	0.75	1.60	0.85
3	0.85	1.75	0.90
4	0.80	1.63	0.83

Table 2 illustrates observations made is step 7 of the procedure.

Table 2 Motion of Various Amplitude Pulses Along a Spring (Round Trip)

Amplitude (cm)	Trial	Time (s)
	1	1.75
15	2	1.66
	3	1.72
	Avg.	1.71

Amplitude (cm)	Trial	Time (s)
	1	1.82
30	2	1.68
	3	1.73
	Avg.	1.74

Amplitude (cm)	Trial	Time (s)
	1	1.55
45	2	1.76
	3	1.67
	Avg.	1.66

Table 3 illustrates observations made is step 8 of the procedure.

Table 3 Motion of Pulses Along a Spring of Various Stretched Lengths (Round Trip)

Length (m)	Trial	Time (s)
	1	1.7
2.0	2	1.66
	3	1.72
	Avg.	1.71

Length (m)	Trial	Time (s)
	1	1.68
3.0	2	1.50
	3	1.59
	Avg.	1.59

Length (m)	Trial	Time (s)
	1	1.41
4.0	2	1.57
	3	1.50
	Avg.	1.49

Table 4 illustrates observations made is step 9 of the procedure.

Table 4 Motion of Pulses Along Various Spring Types (Round Trip)

Spring type	Trial	Time (s)
	1	1.75
heavy	2	1.66
	3	1.72
	Avg.	1.71

Spring type	Trial	Time (s)
	1	1.66
medium	2	1.47
	3	1.54
	Avg.	1.56

Spring type	Trial	Time (s)
	1	1.14
light	2	1.29
	3	1.20
	Avg.	1.21

* Note that the first set of entries in Tables 2, 3, and 4 all represent the same trial, and thus have identical data.

Analysis

Time vs. Pulse

From the data in Table 1, it appears that the time taken for the incident pulse to travel to the other end is equal to the time take for the reflected pulse to return to the beginning, within experimental error. It can be concluded that the speed of the incident pulse is the same as the speed of the reflected pulse.

Time vs. Amplitude

From the data in Table 2, it appears that the amplitude of a pulse does not affect the time required for a pulse to travel from one end to the other and back, within experimental error. It can be concluded that the speed of a pulse is not affected by the amplitude of the pulse.

Time vs. Amount of Stretch

From the data in Table 3, it appears that the amount of stretch in a spring does affect the time required for a pulse to travel from one end to the other and back. It can be concluded that the speed of a pulse is directly related to the tension in the spring, i.e. a higher tension leads to a higher pulse speed. **Table 5** shows the speed for the various lengths and speed is calculated using the formula $v = \frac{d}{t}$.

Table 5 Speed vs. Amount of Stretch in Spring

Length (m)	2.0	3.0	4.0
Distance (m)	4.0	6.0	8.0
Average time (s)	1.71	1.59	1.49
Speed (m/s)	2.34	3.77	5.37

Time vs. Spring Type

From the data in Table 4, it appears that the type of spring does affect the time required for a pulse to travel from one end to the other and back. It can be concluded that the speed of a pulse is inversely related to the "weight" of the spring, (i.e., a higher "weight" leads to a slower pulse speed).

(a) True/False
True (i) Energy may move from one end of the spring to the other.
False (ii) When energy is transferred from one end of a spring to another, the particles of the spring are also transferred.

(b) (i) When the condition of a spring changes (for instance, the amount of stretch in a spring), the speed of the pulse also changes.
(ii) When the amplitude of a pulse changes, the speed of the pulse is unaffected.
(iii) When the pulse is reflected off one end of the material, the speed of the pulse is unaffected.

(c) When an incident pulse reflects off the end of the medium, the reflected pulse is:
(i) out of phase for a fixed-end reflection.
(ii) in phase for a free-end reflection.

Evaluation

(d) The prediction made in step 8 was supported by the observations made and evidence collected. In Table 3, it is clear that the time taken for the pulse to travel from one end to the other and back decreases as the length, and therefore tension, in the spring increases. Since less time is taken and more distance is travelled, the speed of the pulse must be increasing (according to the equation $v = \frac{d}{t}$). The results are shown in Table 5 and clearly indicate that an increase in length/tension in the spring results in an increase in speed of the pulse.

Based on the remaining evidence gathered throughout the experiment, the design of the experiment is adequate since all questions were clearly answered, within experimental error. Distinct changes in times and speeds were noticeable when the length/tension and type of spring being used were changed. However, when the pulse amplitude was changed, no noticeable change in times or speeds for the pulses was observed.

Since the timing was performed using stopwatches, a main source of error in this lab is human reaction time, which can range from as low as 0.20 s to as high as 2.0 s in some people. For this reason, three trials were performed in each case to help minimize this error. Friction between the spring coils and the floor can also cause some of the pulse energy to be dissipated as heat and thus affect the amplitude of the pulse, although this would not affect the speed as indicated by the results.

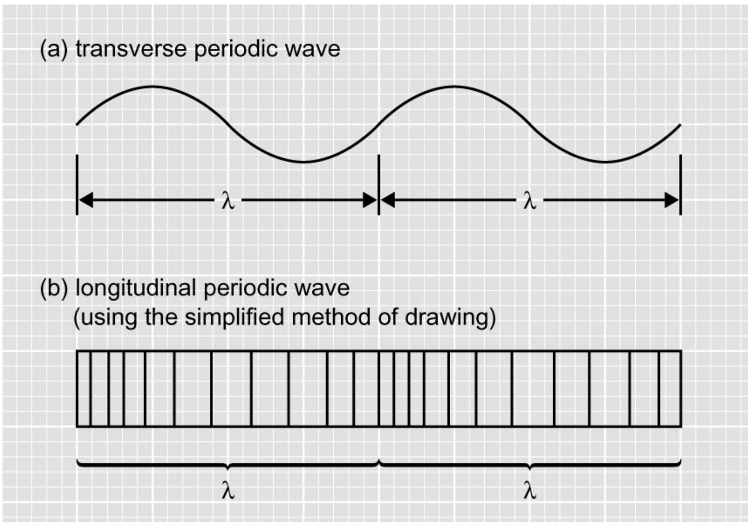
All of the conclusions drawn and answers to questions can be clearly supported with great confidence through the data gathered in this investigation.

PRACTICE

(Page 207)

Understanding Concepts

1. A: crest; B: wavelength; C: amplitude; and D: trough.
2. amplitude = 1.4 cm, λ = 2.8 cm
3. λ = 3.0 cm.
4.



5. (a) λ = 1.7 cm, A = 0.5 cm
   (b) AC = 3.4 cm

$$v = \frac{\Delta d}{\Delta t}$$
$$= \frac{3.4 \text{ cm}}{2.0 \text{ s}}$$
$$v = 1.7 \text{ cm/s}$$

Section 6.2 Questions

(Page 208)

Understanding Concepts

1. Transverse waves are waves in which the particles of the medium move at right angles to the direction of the wave movement. The particles of the medium in a longitudinal wave move parallel to the direction in which the wave is moving.
2. Amplitude is the maximum distance from the rest, or equilibrium position, that the particles are displaced. The wavelength is the distance between successive wave particles that are in phase.
3. (a) Pairs of points that are in phase are B and F, and A and E.
   (b) λ = 5.9 cm.
   (c) $v = \frac{\Delta d}{\Delta t}$

$$= \frac{9.0 \text{ cm}}{0.50 \text{ s}}$$
$$v = 18 \text{ cm/s}$$

4. The amplitude of a wave decreases because some energy is lost to friction.
5. The audience wave is a transverse wave because the particles (the people) move up and down while the wave moves horizontally.
6. There can be many examples of situations that involve some type of waves including swimming, listening to music, making music, talking, and microwave cooking.

Applying Inquiry Skills

7. You could demonstrate a pulse by lining up the six billiard balls in a straight line with approximately 1.0 cm between each ball. Using the cue, hit the end ball against the next ball. After a series of collisions, the first ball will move away from the line.

6.3 THE UNIVERSAL WAVE EQUATION

PRACTICE

(Page 211)

Understanding Concepts

1. (a)
$$v = f\lambda$$
$$= (18 \text{ Hz})(2.7 \text{ m})$$
$$v = 49 \text{ m/s}$$

(b)
$$v = (2.1 \times 10^4 \text{ Hz})(2.0 \times 10^5 \text{ cm})$$
$$= 4.2 \times 10^9 \text{ cm/s or } 4.2 \times 10^7 \text{ m/s}$$

(c)
$$v = \frac{\lambda}{T}$$
$$= \frac{9.0 \times 10^4 \text{ m}}{4.5 \times 10^{-4} \text{ s}}$$
$$v = 2.0 \times 10^8 \text{ m/s}$$

(d)
$$v = \frac{\lambda}{T}$$
$$= \frac{3.4 \times 10^3 \text{ m}}{2.0 \times 10^{-3} \text{ s}}$$
$$v = 1.7 \times 10^6 \text{ m/s}$$

2. (a) from $v = f\lambda$, $f = \dfrac{v}{\lambda}$

(b) from $v = \dfrac{\lambda}{T}$, $T = \dfrac{\lambda}{v}$

(c) from $v = f\lambda$, $\lambda = \dfrac{v}{f}$

(d) from $v = \dfrac{\lambda}{T}$, $\lambda = vT$

Section 6.3 Questions

(Pages 211–212)

Understanding Concepts

1.
$$v = f\lambda$$
$$= (20.0 \text{ Hz})(3.0 \times 10^{-2} \text{ cm})$$
$$v = 6.0 \times 10^{-1} \text{ m/s}$$

2.
$$T = \frac{\lambda}{v}$$
$$= \frac{1.3 \text{ m}}{2.5 \text{ m/s}}$$
$$T = 0.52 \text{ s}$$